Electrotransport of Hydrogen in 1Kh18N10T Chromium-Nickel Steel and Copper at 700-1000°C

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Hydrogen migration induced in 1Kh18N10T steel and copper by an applied electric field was studied at 700-1000°C. The direction of electrotransport of hydrogen in 1Kh18N10T steel depends on the electric current strength. Hydrogen in copper migrates preferentially toward the anode. The results obtained were explained within the framework of the vacancy-electron mechanism of electrotransport, which involves the interaction of hydrogen particles, dissolved in the metal, with vacancies and current carriers. The direction of electrotransport is determined on the one hand by the strength of bonds between hydrogen "atmospheres" and vacancies and on the other hand by the influence of the "electron wind."

It was previously shown [1] that a hydrogen-diffusion flux in α-iron consists of two components with different diffusion characteristics. One of these components, called electropassive, is not influenced by applied electric fields, while the other—electroactive component—is responsible for electrotransport phenomena in iron; the relative magnitude of this component increases with rising temperature.

1Kh18N10T steel was chosen as the experimental material because the diffusion characteristics of this steel’s hydrogen permeability are twice as high as those of α-iron [2]. This made it possible to postulate that the electropassive component of hydrogen flux in this steel is small and that the major part of the total hydrogen-diffusion flux is electroactive, so that hydrogen electrotransport phenomena could be expected to be strongly manifested.

The experiments consisted in measuring changes produced in the hydrogen permeability $P_H$ of a short specimen by passing a direct current through the latter in the direction opposite to, or coinciding with, the direction of the hydrogen-diffusion flux [1]. The hydrogen permeability was measured with a specially constructed volume-measuring apparatus. The quantity of hydrogen permeating through a specimen was estimated from changes in the pressure in a chamber previously evacuated to $1 \times 10^{-4}$ mm Hg. The pressure in the chamber was measured with an automatic MacLeod gauge.

The results of experiments on 1Kh18N10T steel are shown in the figure, in which the applied current density is reduced to a unit length of the specimen. The nominal specimen length $l_0 = 0.6$ cm and the specimen diameter was 0.7 cm. The electric current polarity in the figure is related to the exit-specimen side. The hydrogen pressure on the entry-specimen side was 2.25 atm.

It will be seen that the character of variation in the hydrogen permeability of 1Kh18N10T steel under the influence of electric current is analogous to that observed in the case of α-iron. The only difference is that the direction (sign) of electrotransport of hydrogen in 1Kh18N10T steel varies depending on the applied current strength. Thus, the cross-hatched areas in the figure correspond to conditions under which electrotransport of hydrogen toward the anode takes place.

Dependence of hydrogen permeability of a) 1Kh18N10T steel and b) copper on the strength and direction of the applied electric current.
It was previously postulated [1] that the electrotransport of hydrogen toward the cathode is produced by vacancies migrating toward the negative pole as a result of interaction with the electron flux and dragging with them hydrogen "atmospheres." It was also established that the electropassive component of the hydrogen flux is not influenced by vacancies or current carriers moving in a metal. Anomalies (humps) on graphs relating to the electrotransport of hydrogen in $\alpha$-iron were attributed to hydrogen "atmospheres" breaking away from their carriers (vacancies).

The change in the direction (sign) of electrotransport of hydrogen in 1Kh18N10T steel takes place, as shown in the figure, in the regions in which hydrogen atmospheres break away from vacancies. This makes it possible to postulate that Cottrell (hydrogen) atmospheres broken away from vacancies and constituting the electroactive component of the hydrogen-diffusion flux interact with free electrons in the metal and, as a result, migrate ("are blown by the electron wind") toward the anode. The theory of electron-ion interaction has been adequately expounded in the literature [3, 4]; we need not go into this problem in more detail.

In view of the above considerations it was interesting to carry out experiments on the electrotransport of hydrogen in metals with a reduced capacity for the formation of bonds between vacancies and hydrogen dissolved in a metal-crystal lattice; preferential transport of hydrogen toward the cathode should take place in such metals. One of the metals with weak bonds between dissolved hydrogen and local lattice defects is copper.

Hydrogen embrittlement of the second kind [5] is distinguished by the fact that weak regions are formed in metals only during (not before) deformation at slow strain rates at certain temperature intervals. Numerous theories of hydrogen embrittlement of this kind [6, 7, etc.] give different explanations of the mechanism of this phenomenon. Common to some of these theories is the postulate that the observed dependence of hydrogen embrittlement on strain rate is due to interaction of hydrogen dissolved in the crystal lattice with such defects as dislocations and vacancies, which move under the influence of deformation of a given metal. It can therefore be concluded that, in the case of metals with a reduced susceptibility to hydrogen embrittlement of the second kind, the bond forces between hydrogen dissolved in the crystal lattice and dislocations, vacancies, and other similar defects are weakly manifested.

Hydrogen embrittlement of copper is caused by hydrogen reacting with copper oxide, and this leads to build-up of a high pressure of the products of this reaction at the grain boundaries. Embrittlement due to the presence of oxygen does not disappear or decrease with increasing strain rate, while oxygen-free copper is not susceptible to hydrogen embrittlement [5]. It can therefore be assumed that copper is not subject to hydrogen embrittlement of the second kind; i.e., the bonds between hydrogen dissolved in the regular crystal lattice and local structural defects of the copper are very weak.

The apparatus and the method used to study the electrotransport of hydrogen in copper were similar to those previously described [1]. To prevent the oxidation of copper specimens, their external surfaces were chromium-plated (deposits 100–120 microns thick) and subsequently enamelled. The hydrogen pressure at the entry side was 3 atm.

In spite of the measures taken to prevent oxidation, the specimens rapidly deteriorated and became porous. The values of hydrogen permeability $P_H$ plotted in the figure are therefore overestimated and give a qualitative rather than quantitative picture of electrotransport of hydrogen in copper. (For this reason the computation of the effective charge of hydrogen $Z^H_{eff}$ is not reproduced.)

The electrotransport of hydrogen in copper in the temperature interval studied is directed toward the anode (except for small regions in the range of positive values of electric current). As previously stated, the direction of electrotransport is determined by the strength of bonds between hydrogen atoms and vacancies (displacement toward the cathode) and by electron-ion interaction (displacement toward the anode). When the bonds between hydrogen atmospheres and lattice defects are weak, the decisive part is played by the electron-ion interaction; as a result, the displacement of hydrogen in copper is directed, as was to be expected, toward the anode.

This proves the initial hypothesis that the bonds between hydrogen dissolved in a copper-crystal lattice and mobile local defects are weak. However, it must not be assumed that there is no hydrogen-vacancy interaction. The deviation of hydrogen permeability curves from linearity in the region of positive values of the applied electric current indicates that such an interaction does, in fact, take place. In this case no electron-ion interaction is observed, and the effects of electrotransport of hydrogen in copper can be fully explained from the standpoint of the vacancy-electron mechanism of electrotransport.

Conclusions

1. The direction of electrotransport of hydrogen in 1Kh18N10T chromium-nickel steel at the temperatures and concentrations studied depends on the strength of the applied electric current.

2. Electrotransport of hydrogen in copper at 900–1000°C is directed preferentially toward the anode.

3. The direction of electrotransport of hydrogen in metals is determined by the strength of the bonds between hydrogen atmospheres and vacancies and by the influence of the "electron wind." When the vacancy hydrogen-atmo-